International Journal of Engineering Research (ISSN: 2319-6890)
Volume No.2, Issue No.2, pp: 108-112 01 April 2013

Performance Evaluation of a Nanofluid (CuO-H_2O) Based Low Flux Solar Collector

Lal Kundan, Prashant Sharma
Department of Mechanical Engineering, Thapar University, Patiala-147004, India
kundanlalrana@thapar.edu, prashantsharma89144@gmail.com

Abstract

As the fossil fuels are depleting continuously, we know that solar energy harvesting is a significant potential area for new research dimensions. Sun provides us about 1.9 x 10^8 TWh/yr on the land, of which 1.3 x 10^5 TWh]/yr energy is used. In order to make much use of solar energy on the earth, solar energy harvesting into more usable form (e.g. heat or electricity) by using solar energy collectors is important aspect. A solar collector [1] is a device which transfers the collected solar energy to a fluid which is flowing through it and in contact with it. The performance of collector does not only depends upon how effective the absorber is, but also on how effective the heat transfer is? And on thermal properties (e.g. thermal conductivity, heat capacity) of the fluid which is eing used. In general, the absorption properties of the fluids which are generally used in solar collectors are poor, which in turn limits the efficiency of the solar collector. So, there is a need to use energy efficient heat transfer fluids for high efficiency and performance. A relatively new attempt has been made to increase the performance of the solar collector by using nanofluids. Recently developed a new class of working fluids called Nanofluids, found to be possessing better thermal properties over the hosting fluids, can be a good option in the solar collector [5]. In our research work the CuO-water based nanofluid has been tested in the solar collector and their performance is investigated. It has been found that efficiency if the solar collector is increased by 4-6% compared to water.

Keywords- Solar Collectors, Low Flux Solar Collectors, Nanofluids and Ethylene Glycol

I. INTRODUCTION

A Solar collector is used to collect the solar energy and transfers the collected solar energy to a fluid passing in contact with it, so it is always a matter of investigation to know that how efficiently solar collectors are converting solar energy into thermal energy [9]. Solar collectors are classified as: Non-Concentrating or flat plate type solar collectors and Concentrating Solar Collectors. Flat plate collectors are very simple in construction and are mostly used as household equipment as water heater, air heater, and solar cooker whereas, concentrating solar collectors are mostly used for power generation, heating up water with higher mass flow rate [7]. Concentrating Solar Collectors (Praboloid Dish, Parabolic Trough, Heileostat) are more efficient then flat plate collectors but, on the other hand they require a tracking system and they have also higher installation cost compared to flat plate collectors.

The performance of solar collector depends upon the physical properties of the fluid flowing through it. It has been found that the conventional fluids used in solar collectors suffer from poor thermal properties. A new class of working fluids called "Nanofluid" can be used instead of conventional fluids, which have the improved thermal properties and thereby increase the thermal performance of the solar collector. The term Nanofluid is coined by Choi [2]. The suspension of nano-particles into the base fluids or conventional fluids is known as Nanofluids. Nanomaterial have unique mechanical, optical, electrical, magnetic and thermal properties in which average size of the nanoparticles is below 100 nm. A very small amount of nanoparticles when dispersed in any host fluids (e.g. water, oil, ethylene glycol) can improve the thermal properties of fluids dramatically. Commonly used material making nanofluids are as: oxide ceramics (Al_2O_3, CuO), nitride ceramics (AlN, SiN), carbide ceramics (SiC, TiC), metals (Cu, Ag, Au), semiconductors (TiO_2, SiC), carbon nanotubes, composite materials ($Al_{70}Cu_{30}$). Nanoparticles can be manufactured by mainly two processes; those are Physical Processes and Chemical Processes. Physical Processes include Inert Gas Condensation (IGC) and mechanical grinding where as Chemical Processes include Chemical Vapor Deposition (CVD), Chemical precipitation and micro emulsion. For making Nanofluids, nanoparticles are suspended in conventional heat transfer fluids by two methods called Single Step Method and Two Step Method. In Single Step method making and dispersion of nanoparticle happens simultaneously where as Two Step method first nanoparticles are fabricated and then nanoparticles dispersed into the base fluids.

II. DIRECT ABSORPTION SOLAR COLLECTOR

To enhance the efficiency of the solar collectors the system is made to directly absorb the solar energy within the fluid volume and thus so called Direct Absorption Solar Collector (DASC) [3]. The schematic diagram is shown in Fig. 1. This diagram shows the comparison between DASC and conventional flat plate collector. In conventional flat plate collector fluid absorbs heat energy through surface absorber (fluid flow through pipes) where as in DASC solar heat is directly absorbed by the fluid. So, in turn DASC cuts down the heat resistance for the conventional flat plate collector [4]. The equation given below shows that the total resistance to heat transfer involved in conventional flat plate collector is much higher than DASC system.

$$Ra_1 + Ra_2 < Rb_1 + Rb_2 + Rb_3$$

Where, $Rb_2 = Rcv + Rcd$

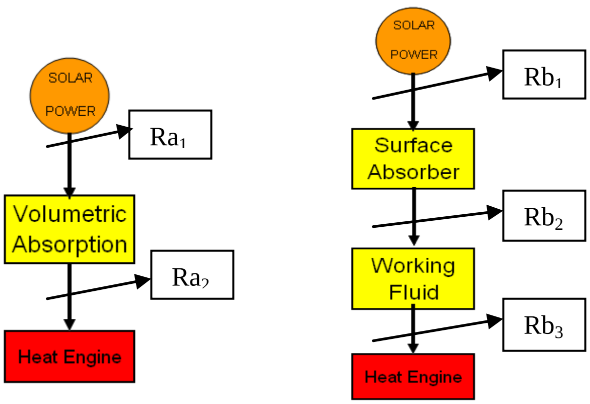


Fig. 1: DASC

III. PREPARATION OF NANOFLUIDS

CuO nanoparticles are synthesized by precipitation method. In this method Cupric Nitrate [Cu $(NO_3)_2.3H_2O$] is dissolved in distilled water then Sodium Carbonate [Na_2CO_3 (1M)] is mixed with the above solution to adjust the pH value of the solution to 10. The product is then aged with the mother liquor at room temperature for 12h [8, 9]. The resultant product is then filtered, washed with distilled water using centrifuge. After washing the product is dried at 60˚C for 24 hrs and then calcined in Muffel furnace at 350˚C for 4 hr. Finally characterization is done with the help of XRD which shows that final product so formed is CuO and average size of the particles is around 80 nm confirmed by SEM.

Fig. 2: CuO nanoparticles

To prepare the CuO nanofluid, there is a need to determine the weight of CuO for different concentration. The weight of CuO can be evaluated by using the standard expression.

$$\varphi = V_P / V_{eff}$$

Where, $V_P = W_P / \rho_P$

$V_{eff} = V_P + V_f$, $V_f = W_f / \rho_f$

Quantity of Base fluid (Water), V_f = 500ml

Density of CuO particles, ρ_P = 6.31 gm/cm^3

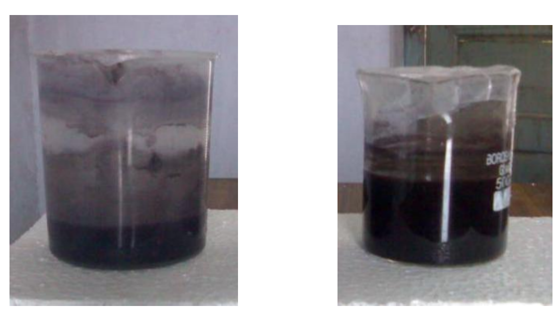
Density of water, ρ_f = 1000 kg/m^3

Table 1 the weight requirement of CuO particles to prepare the nanofluid of different concentration.

Φ	0.005	0.05
W_p (gms)	0.157	1.57

Table 1

Now, CuO particles of required amount are put into a container, and then water is poured into it. The solution then put on the sonicator, and sonication is done for 2 to 3 hour to ensure the uniform dispersion of CuO nanoparticles in the water, after sonication the required nanofluid solution is ready for the application. The probe type sonicator is used for the sonication of nanofluid (Lab Oscar Ultrasonicator). The samples of prepared nanofluids for two concentrations are shown in Fig. 2.



A. B.

Fig. 3: Nanofluids

(ISSN: 2319-6890)
01 April 2013

A. (CuO-H_2O) Nanofluid (with 0.005% volume Concentration)
B. (CuO-H_2O) Nanofluid (with 0.05% volume Concentration)

IV. EXPERIMENTAL SET-UP

The mini channel geometry is selected to minimize the amount of nanofluid needed for the test. In this set-up CuO – H_2O based nanofluid is used. An Infusion Set is used to have a constant flow of nanofluid. The collector glazing is a low reflectance glass. In the apparatus, copper plate is black painted to increase the absorption capacity of the plate. This is a volume absorption system rather than a surface absorption system, as the solar energy is directly absorbed within the fluid volume. This is also called Direct Absorption Solar Collector. The collector geometry area is (0.24 x 0.24 m^2). Pyranometer (Kipp and zonen) was used for calculating the global solar irradiation values .

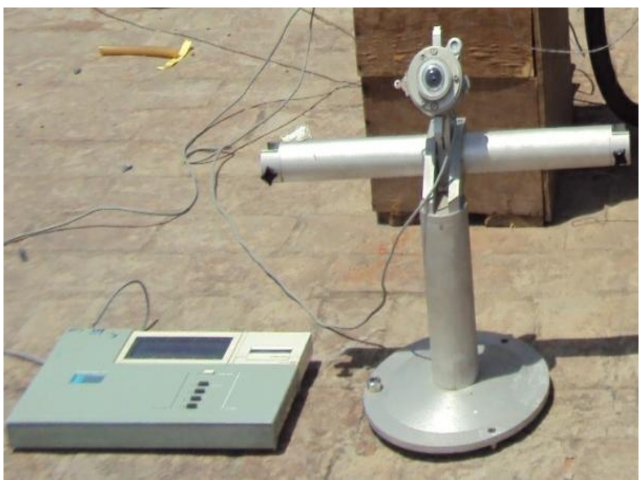


Fig. 4 Kipp and zonen pyranometer

Experiment is performed using different mass flow rate (60 ml/hr, 80 ml/hr and 100 ml/hr) of nanofluids and with different volume fraction (0.05%, 0.005%) of nanoparticles in nanofluids.

Fig. 5: Pictures of set - up

V. RESULTS AND DISCUSSIONS

A. Efficiency variation for different mass flow rates

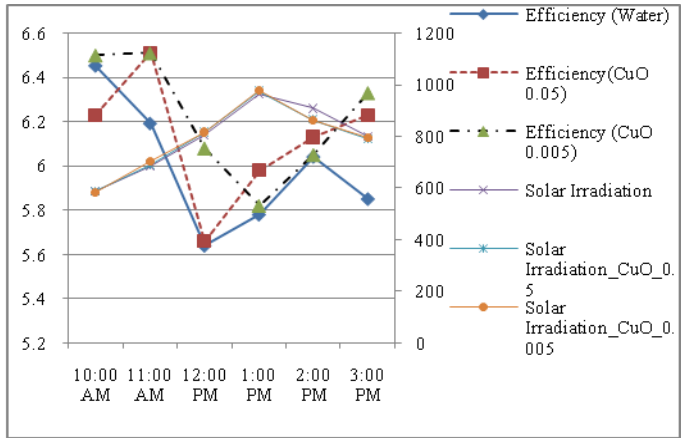


Fig. 5: Efficiency comparison for mass flow rate 60 ml/hr

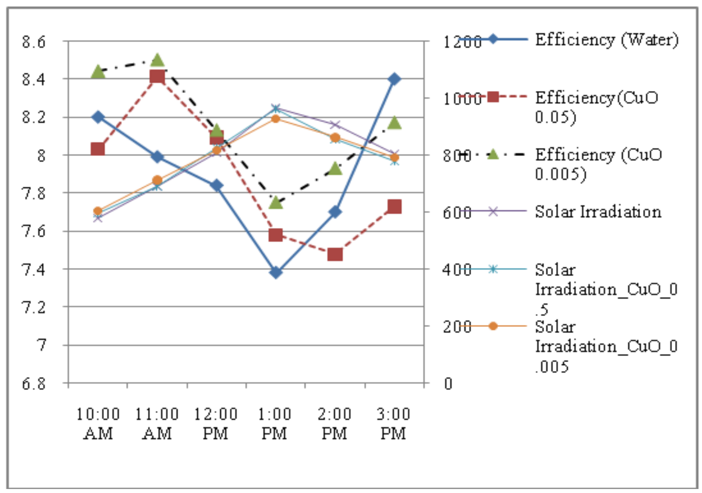


Fig. 6: Efficiency comparison for mass flow rate 80 ml/hr

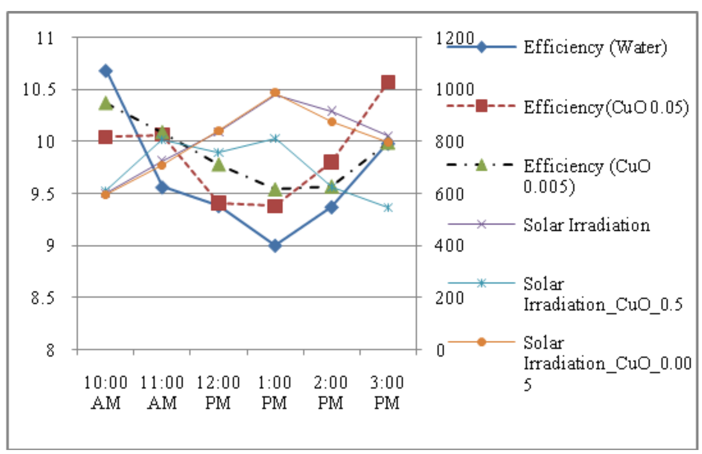


Fig. 7: Efficiency comparison for mass flow rate 100 ml/hr

All the curves show that collector efficiency is a function of mass flow rate and temperature difference of the nanofluids. As temperature difference of CuO-H_2O nanofluid increases, collector efficiency also increases for same mass flow rate. This is because CuO nanofluid absorbs more heat than water. As mass flow rate increases collector efficiency increases for both water as well as CuO nanofluid. Also the surface area of CuO nanoparticle is higher due to extremely small size, which makes nanofluid based solar collector more efficient. These variations of efficiency are shown in Fig. 4, Fig. 5 and Fig. 6. When CuO nanoparticles are suspended in to water then due to the higher optical properties heat absorption capacity of nanofluid increases which give a higher temperature difference. The density of the CuO is higher than water, so after suspension the heat capacity of nanofluid increases, which in turn enhance the collector efficiency.

Thermal properties of nanofluids very much depend on size as well as volume fraction of nanoparticles in the base fluid. The heat transfer characteristics of nanofluids also depend on the sonication time of nanoparticles and the quality of sonication used. So, as stated above CuO has higher value of thermal conductivity and thermo physical characteristics e.g. density, viscosity etc. which enhance the heat absorption capacity, the specific heat capacity and heat carrying properties of nanofluids.

It can be observed that same as the temperature difference collector efficiency of the nanofluid increases at lower volume fraction. Higher the volume concentration higher will be the density, viscosity as well as heat capacity. But here the collector efficiency is lesser in case of higher volume concentration, so as stated above nanofluids confronts the problem of settling down of nanoparticles as volume fraction of nanoparticle increases. So, for higher volume concentration sonication time will be more, so as nanoparticles settle down nanofluid works as the conventional fluid. This is a demerit of nanofluids.

Followings are the equations used to evaluate the performance of the solar collector.

Heat Absorbed by Solar Collector

$Qa = m\ C\ (T_2 – T_1)$

Total Average Solar Radiation fall on Solar Collector

$Q_i = G_T A C_r$

$\eta = m\ C\ (T_2 - T_1) / G_T A C_r$

$m = \rho \text{ x } v$

Expressions for nanofluids

$\eta = m\ C_{eff}(T_2 - T_1) / G_T A C_r$

$m = \rho_{eff} \text{ x } v$

$\rho_{eff} = (1 – \varphi_p)\ \rho_f + \varphi_p \rho_p$

$\varphi_p = V_p/(V_p + V_f$

$C_{eff} = \{(1 – \varphi_p)\ \rho_f\ c_f + \varphi_p \rho_p c_p\} / \rho_{eff}$

Where Qa - Heat Absorbed

m – Mass flow rate of liquid in collector

C – Specific heat of medium used in solar collector

Q_i – Incident Solar Irradiation on the collector

G_T – Solar Irradiation

A – Collector Area

Cr – Correction factor

η – Collector Efficiency

C_{eff} – effective specific heat of nanofluid

ρ_{eff} – effective density of nanofluid

φ_p – volume fraction of nanoparticles in the base fluid

c_f – specifiv heat of base fluid

ρ_p – density of nanoparticle

c_p – specific heat of nanoparticle

ρ_f – density of base fluid

All the data is take in standard SI units for the efficiency calculation.

VI. CONCLUSION

This experiment is a simplified analysis which shows that how a nanofluid-based direct absorption solar thermal system (DASC) will perform compare to a conventional one? The concluding points of this work are as follows:

1. By using CuO nanofluids in DASC efficiency enhancement on the order of 4 – 6 %, when compared to water.
2. CuO nanofluid with 0.005% volume fraction posses 2 – 2.5 % of efficiency improvement than 0.05% volume fraction.
3. One of the main reasons of getting higher efficiency is the very small particle size, which enhances the absorption capacity of nanofluids so, improvement in efficiency is observed.
4. There are also some demerits associated with nanofluids e.g. the settling of the nanoparticles in the base fluid, preparation and testing of nanoparticles are very much costly, which needs to be taken into consideration.
5. By overcoming the above problems the improvement of collector efficiency can be achieved up to 10 – 15 %.

Area of application of nanofluids in solar energy is a very new research field. There are also some contradictions in the results of some research work as it is the initial phase of implementing nanofluids in solar energy. So, there is a necessity to conduct more experiments and do their validation by providing theoretical support. There is a need to investigate further efficiency of solar collector and to obtain firm and authenticate

results. So, it can be concluded that nanofluids have a good potential in solar thermal application and nanofluid can be a good answer for the heat transfer limitation of conventional heat transfer fluids.

REFERENCES

[1] Goswami, Yogi.D, Kreith, Frank, and Kreider, Jan F., Principles of Solar Engineering, 2nd edition. Taylor and Francis, Philadelphia, PA, (2000)

[2] Das.K.S, Choi.S.U.S, YU.W, Pradeep.T, Nanofluids Science and Technology, ISBN 978-0-470-07473-2, Page (1-30)

[3] Minardi.J.E, Chuang.H.N, Solar Energy 17, 179 (1975)

[4] Otanicar.T.P, Phelan.P.E, Prasher.R.S, Rosengarton.G, Taylor.R.A, Nanofluid – Based direct absorption solar collector, (2010)

[5] Taylor.R.A, Phelan.P.E, Otanicar.T.P, Walker.C.A, Nguyen.M, Trimble.S, Prasher.R, Applicability of Nanofluids in high flux solar collectors, Journal of Renewable and Sustainable Energy 3,023104 (2011)

[6] Kalogirou.S.A, Solar Thermal Collectors and Applications, Progress in Energy and Combustion Science, 30 (2004) 231 – 295.

[7] Zhou.K, Wang.R, Xu.B, Li.Y, Synthesis, Characterization and catalytic properties of CuO nano crystals with various shapes, Institute of Physics Publishing Ltd., Printed at UK, (2006)

[8] Sukhatme.S.P, Solar Energy (Principles of Thermal Collection and Storage), Tata Mcgraw Hill, ISBN 0-07-451946-8, (1984).

[9] Khanafer.K and Vafai.K, A Critical Synthesis of thermo physical characteristics of Nanofluids, International Journal of Heat and Mass Transfer (Under press), (2011)

AUTHOR

Author – Lal Kundan , Master's of Engineering (Thermal Engineering), Mechanical Engineering Department, Thapar University (Patiala) -147004, India, kundanlalrana@thapar.edu
Correspondence Author –
Lal Kundan, kundanlalrana@thapar.edu